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Developing Threshold Conception in Statics

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Abstract

The study and practice of engineering involves complex problem solving which requires the application and integration of fundamental principles of mathematics and science. The development of the skill needed to do this effectively and efficiently is a journey from novice to expert that begins in the undergraduate curriculum. The more analytical aspects of complex problem solving are often introduced in statics courses.

Referring to the example of a computer programming class in their book Overcoming Barriers to Student Understanding: Threshold concepts and troublesome knowledge, Meyer and Land accurately summarize what happens as, "…students may grasp the concepts of class, objects, tables, arrays and recursion, but they may not appreciate the deeper threshold conception, the underlying 'game' as it were, of the interaction of all these elements in a process of ever-increasing complexity." In a typical statics class, my experience has been that 1 of every 5 students demonstrates a strong ability to solve complex problems, 1 of every 5 students demonstrates a strong inability, and the rest fall somewhere in between. In an effort to facilitate an increase in the number of students demonstrating a strong ability to solve complex problems, I instituted teaching techniques to support knowledge organization and the development of metacognitive skills.

Teamwork, in-class problem solving, and "think-alouds" are three strategies with strong indicators of their utility in supporting learning. These strategies were combined throughout the course. Student work was collected to assess the development of a deeper threshold conception of engineering problem solving. Students were also asked to assess their own progress in a written survey at the end of the semester. This paper discusses the development of this project and its execution, assessment methods, and preliminary outcomes during the first semester of its implementation.

Introduction

The threshold concept model developed in the United Kingdom during a study to identify characteristics of strong teaching and learning environments[1]. Since then, threshold concepts have emerged as a research methodology to uncover the reasons behind the difficulty faced by novices who attempt to tackle complex disciplinary concepts.

The study and practice of engineering involves complex problem solving which requires the application and integration of fundamental principles of mathematics and science. The development of the skill needed to solve complex problems effectively and efficiently is a journey from novice to expert that begins in the undergraduate curriculum. Therefore, the threshold concept model is well suited for engineering education. In fact, there is a growing body of knowledge and literature related to the exploration of threshold concepts in a variety of engineering disciplines, including chemical, civil, electrical, and environmental[2]. In mechanical engineering, and more specifically statics education, the current available literature focuses on the use of an online tutorial to engage students in exploring threshold concepts[2].

Threshold concepts have been found to share seven characteristics. Here, I provide some explanation of each characteristic and how each relates to this project.

- *Integrative*: "Threshold concepts, once learned, are likely to bring together different aspects of the subject that previously did not appear, to the student, to be related[3]." This is probably the most obvious connection this work due to the inherent need to apply fundamental principles of mathematics and science when solving complex engineering problems. For example, a statics problem may involve trigonometry, vector algebra, and Newton's second law of motion.
- *Transformative*: Threshold concepts are "akin to a portal, opening up a new and previously inaccessible way of thinking about something . . . it represents a transformed way of understanding, or interpreting, or viewing . . . without which the learner cannot progress[4]." This is the crux of my research question; is solving complex problems a threshold concept and therefore a transformative experience that begins in the statics course?
- *Irreversible*: "Given their transformative potential, threshold concepts are also likely to be irreversible, i.e. they are difficult to unlearn[3]." If solving complex problems is a threshold concept, once students embrace a systematic approach to solving problems they will improve and will not revert.
- *Bounded*: "A threshold concept will probably delineate a particular conceptual space, serving a specific and limited purpose[5]." To quote the textbook used for this course, "The most effective way of learning the principles of engineering mechanics is to solve problems. To be successful at this, it is important to always present the work in a logical and orderly manner…[6]" This methodical problem solving approach is a conceptual space of engineers.
- *Re-constitutive*: "In short, there is no simple passage in learning from 'easy' to 'difficult'; mastery of a threshold concept often involves messy journeys back, forth and across conceptual terrain[7]". Experience, both as a student and as a teacher, has taught me that learning to solve problems is a messy process marked by periods of success and failure. This quote from a student captures the prevailing sentiment:

  Its really the beginning path you go down for me. Sometimes when solving a problem I'll get disheartened when I do so much work then got it wrong. Other times its motivation

- *Discursive*: "It is hard to imagine any shift in perspective that is not simultaneously accompanied by (or occasioned through) an extension of the student's use of language. Through this elaboration of discourse new thinking is brought into being, expressed, reflected upon and communicated. This extension of language might be acquired, for example, from that in use within a specific discipline, language community or community of practice, or it might, of course, be self-generated. It might involve natural language, formal language or symbolic language.[8]" The language extension of engineers learning to solve problems includes some natural language, formal disciplinary language, and symbolic language. As explained by Meyer and Land[8], language encompasses common words (natural language) with new meanings (formal disciplinary language) and the corresponding governing equations (symbolic language). Take the term moment as an example. Moment means the tendency to rotate in engineering, is the same as torque in physics, but is different from the common meaning of instant. The symbolic language of moment is $M = F * d$. Discerning all of this information and figuring out how it is all integrated can be challenging for many students.

- *Troublesome*: A threshold concept is often bothersome to students as it "entails a letting go of earlier, comfortable positions and encountering less familiar and sometimes disconcerting new territory[9]." One student mentioned in conversation that this course was their first encounter with problems requiring intermediate solution steps that build upon one another to a final solution.

Implementation/Course Overview

As mentioned earlier, the journey from novice to expert for solving complex engineering problems often begins during undergraduate study. Many programs will begin this journey with first year students in the form of a hands-on introductory engineering design project, while the more analytical aspects of complex problem solving are introduced in the second year. This often occurs in Engineering Mechanics: Statics course, as is the case at Elon University. The course is offered each fall semester. In my work, I have attempted to combine ideas and best practices to support student learning and foster the students' development to expert problem solvers.

Teamwork/peer learning, in-class problem solving, and "think-alouds" are well known strategies with strong indications of their utility in supporting learning. Since engineering mechanics encompasses the application of principles previously covered in first year physics, it is important to activate that prior knowledge[10]. However, these authors caution that accurate, activated knowledge still may not be sufficient since this knowledge may exist in different forms; for example, declarative knowledge ("knowledge of facts and concepts that can be stated") versus procedural knowledge ("knowing how and knowing when to apply various procedures, methods, theories, styles, or approaches")[10].

This project attempted to create an environment where the above approaches were combined to support the development of a deeper threshold conception of solving engineering problems. In a typical week, two class periods consisted of traditional instruction via lecture and instructor-led example problems. The third class period consisted of teams of students solving selected textbook problems which integrated concepts from the previous classes. On those days, students were tasked with working together in teams of three to solve textbook problems in class on custom desk whiteboards and my only instruction was to think about the problems in relation to those we solved together earlier in the week (another form of prior knowledge activation).

Assessment Methods

Data collection for this project took place during the scheduled meeting times and consisted of the normal coursework for Engineering Mechanics: Statics, so participants were not asked to complete any additional activities or assignments. More specifically, data collection included homework assignments, semester tests, the final exam, end-of-course assessment, and video recordings of in-class team problem solving ("think alouds"). Homework assignments included traditional problem sets as well as opportunities for self reflection following semester tests.

Outcomes

With a small group of consenting respondents (17) in the first semester of implementation of this approach, this communication is intended to provide early evidence of the utility of this threshold concept model in helping students develop a deeper threshold conception in solving complex problems. Therefore, homework assignments specifically intended for post-test self reflection (exam wrapper[10]), semester tests, and end-of-course assessment (closing questions) are discussed here. Samples of the exam wrapper and the end-of-course assessment are provided in Figure 1 and Figure 2. Also, the problem solving rubric used for scoring students' ability to apply relevant principles is shown in Figure 3.

Following the first semester test, 57.1% of consenting respondents indicated they did not know how to approach one or more problems. By the end of the course, immediately following the third and final semester test, 62.8% of consenting respondents indicated that the greatest challenge to arriving at correct solutions to problems was knowing how to start. Difficulty knowing how to approach problems correlates to trouble applying relevant principles to problem attributes, either verbally or mathematically (declarative knowledge). When tests one and three were re-scored for proficiency in the "Apply" problem solving step, there was no significant change in performance (an average "Apply" score of 3.69 on the first test and 3.57 on the third test).

The result that at least 57.1% of students encountered difficulty determining the correct problem solving approach throughout the course suggests that applying relevant principles to problem attributes is a threshold concept for second year engineering students. The steady performance of students applying principles on tests is further support of this notion. Since the course material typically grows in complexity throughout a semester, the increase in the percentage of students encountering difficulty applying principles to specific problems is not surprising. The increase and nominal change in "Apply" scores also indicates that students did not cross this threshold.

Did students make some progress in developing a deeper threshold conception? Did students improve their ability to solve problems? Yes. The end-of-course survey included a description of threshold conception. Students were then asked to assess their current ability to organize knowledge and apply a "deeper threshold conception" in solving engineering problems as compared to the start of the course. A few samples illustrating the range of responses are given in Table 1. Of consenting respondents, 56.3% indicated that they felt their ability had improved in some way.

The analysis also revealed that more can be done to support students in their development of deeper threshold conception. First, several students indicated (and I observed) some individuals refused to contribute to the team efforts. The reasons cited in the assessment tools for this lack of engagement ranged from lack of motivation to feelings of frustration to perceived mastery of the material. Therefore, the importance of peer learning must be emphasized and individual accountability to the team must be encouraged in the future. More emphasis must also be placed on the importance of using a methodical problem solving approach; modeling during lecture is not enough. Providing the students with the problem solving rubric used to score their tests for this study would help. Last, the class period often ended before problems were finished or before teams had an opportunity to share their results with the rest of the class. Therefore, time must be allotted for closure and reflection following each team problem solving effort. This will likely reduce frustration and allow more exploration of the thought processes that occur during problem solving.

Conclusions

The learning process that engineering students experience while solving complex problems in statics is characteristic of the threshold concept model. When examined in terms of a four-step problem solving methodology (set-up, apply, solve, and finish), the early analysis of data collected in this study revealed that the task of connecting theory with problem attributes to devise a problem solving strategy during the "apply" step (procedural knowledge) is the most troublesome for students. Although the majority of students involved in this study did not successfully cross this threshold, gains were made in the journey to becoming expert problem solvers. Therefore, it may be concluded that connecting theory to practice in solving complex problems is a threshold concept and in-class problem solving, peer learning, and self-assessment are effective strategies for students to develop deeper threshold conception in their ultimate quest to become expert problem solvers.

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Engineering Exam Wrapper

This reflection activity is designed to give you a chance to reflect on your exam performance and, more important, on the effectiveness of your exam preparation. Please answer the questions honestly and sincerely. Your responses will be collected to assess how we can work together to support your learning. Your completed form will be returned in advance of the next exam to help guide your preparation for that exam.

1. Approximately how much time did you spend preparing for this exam? ____________________
2. What percentage of your test-preparation time was spent in each of these activities? NOTE: Your percentages should total 100.

a. Reading relevant textbook sections for the first time	
b. Re-reading relevant textbook sections	
c. Reviewing homework solutions	
d. Solving problems purely for practice	
e. Reviewing your own notes	
f. Studying and discussing concepts with team members	
g. Other; please specify:	

3. Now that you have reviewed your graded exam, estimate the percentage of points lost due to each of the following (again, make sure the percentages total 100):

a. Arithmetic errors	
b. Lack of understanding the concept(s)	
c. Not knowing how to approach the problem	
d. Obvious mistakes in problem solving	
e. Other; please specify:	

4. Based on your responses to the questions above, name at least three specific things you plan to do differently in preparing for the next exam. For instance, will you spend more time studying, change a specific study habit, try a new approach (if so, name it), work to strengthen math skills, solve more practice problems, study more collaboratively with your team, or something else?

5. What can Dr. ____ do to help support your learning and your preparation for the next exam?

Adapted from:
Ambrose, Susan A., Michael A. Bridges, Michele DiPietro, Marsha C. Lovett, and Marie K. Norman. *How Learning Works*. San Francisco, CA: Jossey-Bass, 2010.

Figure 1. Self-assessment administered after semester tests

Threshold Concepts in Engineering Closing Questions

1. What would you say has been the most productive way for you to learn to solve engineering problems? (for example, attending lecture, taking notes, reading the textbook, working through homework problems with your team, working problems alone, preparing for exams, etc.)

2. What has not been helpful or productive as you have learned to be a better problem solver?

3. What are the greatest challenges in coming up with correct solution to problems?

4. How do you use the answers to selected problems as a resource?

5. How do you use the textbook companion website as a resource?

6. In what ways, has the course affected your understanding of or interest in engineering?

7. In what ways do you see your experiences in this class impacting your future?

8. The following quote by Meyer and Land (2008), referring to the example of a computer programming class, indicates how this study supports the idea of deeper threshold conception: "…students may grasp the concepts of class, objects, tables, arrays and recursion, but they may not appreciate the deeper threshold conception, the underlying 'game' as it were, of the interaction of all these elements in a process of ever-increasing complexity."

   Assess your current ability to organize knowledge and apply a "deeper threshold conception" in solving engineering problems as compared to the start of the course.

9. These questions have attempted to address the role various resources have had on your learning of engineering. Have I missed anything?

Figure 2. Self-assessment administered at the end of the course

STEP	PERFORMANCE	SCORE and FEEDBACK
Set-up	+1 Rewrite the problem statement and redraw the picture from the text +3 Identify some problem data and draw a partial FBD +5 Identify all problem data (given & find) and draw complete FBD	
Apply	+1 Little representation of how the problem attributes link to the principles +3 Relevant principles noted, but not linked to the problem OR key/some relevant principles omitted +5 Note relevant principles OPTION 1: verbally link problem attributes to the principles OPTION 2: mathematically link problem attributes to the principles	
Solve	+1 Little work shown +3 Random progression/several omitted steps to a correct answer +5 Clear, step-by-step logical progression to a correct answer	
Finish	+1 One of the five +3 Three of the five +5 Five of the five: answers boxed, answers reported with no more than 3 significant figures, written on engineering paper, stapled, name	
		TOTAL SCORE:

Figure 3. Problem solving rubric

Table 1. Student responses to the prompt, "Assess your current ability to organize knowledge and apply a 'deeper threshold conception' in solving engineering problems as compared to the start of the course."

I feel as if I haven't really grown as far as developing an ability to assess a deeper conception in solving these problems.
I recognize the deeper concepts that are present and their great complexity, but I don't have a strong understanding.
Better now
It's better
I have been trying to achieve a deeper threshold conception of the course but may only be half way there.
This ability has vastly improved. Through practice and increased understanding of some of the components which are integral in engineering situations my understanding has advanced.